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Comments:

This is responsive to the March 3, 2004 telephone interview between Examiner Rickman and Tarik Nabi. The requested verified translations of the priority documents are hereby provided by facsimile to Examiner Rickman.

Tarik M. Nabi
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Sent by:

TRANSLATOR'S VERIFICATION

I hereby declare and state that I am knowledgeable of each of the Japanese and English languages and that I made and reviewed the attached translation of the certified copy of Japanese Patent Application No. 2001-078630, filed on March 19, 2001 from the Japanese language into the English language, and that I believe my attached translation to be accurate, true and correct to the best of my knowledge and ability.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of this application or any patent issued thereon.

Date: February 3, 2004

Kiyoko Ishimura

(Signature)

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JAPAN PATENT OFFICE

This is to certify that the annexed is a true copy of the following application as filed with this Office.

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Applicant(s): HITACHI MAXELL, LTD.

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[TITLE OF THE DOCUMENT] Specification

[TITLE OF THE INVENTION] MAGNETIC RECORDING MEDIUM AND MAGNETIC RECORDING APPARATUS

[CLAIMS]

[Claim 1] A magnetic recording medium characterized by comprising:

an underlying base layer;

a recording layer which is formed of a ferromagnetic material;

a coercive force enhancing layer which exists between the underlying base layer and the recording layer while making contact with the underlying base layer, which is formed of a ferromagnetic material, and which increases a coercive force of the recording layer; and

a non-magnetic layer which exists between the recording layer and the coercive force enhancing layer,

wherein a difference between lattice spacing on an orientation plane of the coercive force enhancing layer and lattice spacing on an orientation plane of the underlying base layer is smaller than a difference between lattice spacing on an orientation plane of the recording layer and the lattice spacing on the orientation plane of the underlying base layer.

[Claim 2] The magnetic recording medium according to claim 1, characterized in that the following relationship

is satisfied:

$\Delta 1 > \Delta 2$

provided that the lattice spacing on the orientation plane of the recording layer is defined as a_1, the lattice spacing on the orientation plane of the coercive force enhancing layer is defined as a_2, the lattice spacing on the orientation plane of the underlying base layer is defined as a_3, and mismatches $\Delta 1$, $\Delta 2$ are defined as follows respectively:

$\Delta 1 = |(a_1 - a_3)/a_3| \times 100$

$\Delta 2 = |(a_2 - a_3)/a_3| \times 100.$

[Claim 3] The magnetic recording medium according to claim 2, characterized in that the mismatches $\Delta 1$, $\Delta 2$ further satisfy the following relationships:

$\Delta 2 < \Delta 1 < 10.25$; and

$(5/10.25) < \Delta 1/\Delta 2 < 1.$

[Claim 4] The magnetic recording medium according to any one of claims 1 to 3, characterized in that the coercive force enhancing layer has the same crystal structure as that of the recording layer.

[Claim 5] The magnetic recording medium according to any one of claims 1 to 4, characterized in that a ratio of magnetic element contained in the coercive force enhancing layer is larger than a ratio of magnetic element contained in the recording layer.

[Claim 6] The magnetic recording medium according to any one of claims 1 to 5, characterized in that a relationship of Ms1 > Ms2 is satisfied provided that saturation magnetization of the coercive force enhancing layer is represented by Ms1, and saturation magnetization of the recording layer is represented by Ms2.

[Claim 7] The magnetic recording medium according to any one of claims 1 to 6, characterized in that the coercive force enhancing layer is formed of one selected from the group consisting of Co, Ni, Fe, and CoNiFe alloy.

[Claim 8] The magnetic recording medium according to any one of claims 1 to 6, characterized in that the coercive force enhancing layer is formed of an alloy containing a transition metal and Co, Ni, or Fe.

[Claim 9] The magnetic recording medium according to any one of claims 1 to 8, characterized in that the non-magnetic layer is formed of Ru.

[Claim 10] The magnetic recording medium according to any one of claims 1 to 9, characterized by further comprising a substrate, wherein the underlying base layer is provided on the substrate.

[Claim 11] A magnetic recording medium comprising:

a recording layer which is formed of a ferromagnetic material;

a coercive force enhancing layer which is formed of a ferromagnetic material and which increases a coercive force of recording layer; and

a non-magnetic layer which exists between the recording layer and the coercive force enhancing layer.

[Claim 12] The magnetic recording medium according to claim 11, characterized in that the coercive force enhancing layer also functions as a coercive force enhancing layer which stabilizes magnetization of the recording layer.

[Claim 13] The magnetic recording medium according to claim 11 or 12, characterized in that a magnetization curve of the magnetic recording medium with respect to an external magnetic field exhibits a hysteresis loop, a point, at which a rate of change of magnetization with respect to the external magnetic field exhibits a local maximum when the external magnetic field is lowered after magnetization is saturated, exists in a positive area of the external magnetic field, and an exchange coupling magnetic field, which is determined from the magnetization curve, is not less than 1 kOe.

[Claim 14] The magnetic recording medium according to any one of claims 11 to 13, characterized in that:

the recording layer and the coercive force enhancing layer include Co, Ni, or Fe; and

a ratio of magnetic element contained in the coercive force enhancing layer is larger than a ratio of magnetic element contained in the recording layer.

[Claim 15] The magnetic recording medium according to claim 1 or 11, characterized in that the recording layer has a magnetization in the in-plane direction.

[Claim 16] A magnetic recording apparatus characterized by comprising:

the magnetic recording medium according to claim 1 or 11;

a magnetic head which is used to record or reproduce information on the magnetic recording medium; and

a driving unit which drives the magnetic recording medium with respect to the magnetic head.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[TECHNICAL FIELD TO WHICH THE INVENTION BELONGS]

The present invention relates to a magnetic recording medium and a magnetic recording apparatus. In particular, the present invention relates to an in-plane magnetic recording medium which is excellent in thermal stability and which is preferable for high density recording, and a magnetic recording apparatus which is installed with the in-plane magnetic recording medium.

[0002]

[PRIOR ART]

Accompanying with the recent progress of the advanced information society, the multimedia, with which not only the character information but also the voice and image information can be processed at a high speed, are popularized. A magnetic recording apparatus, which is installed to a computer or the like, is known as one of the multimedia. At present, the development is advanced in order that the magnetic recording apparatus is miniaturized while improving the recording density of such a magnetic recording apparatus.

[0003]

A typical magnetic recording apparatus includes a plurality of magnetic disks which are rotatably installed onto a spindle. Each of the magnetic disks comprises a substrate and a magnetic film formed thereon. Information is recorded by forming a magnetic domain having a specified magnetization direction in the magnetic film.

[0004]

In order to realize the high density recording with the magnetic recording apparatus as described above, it is demanded that the diameter of grains for constructing the magnetic film is made fine and minute and the interaction between the respective grains is lowered. However, a problem arises such that the thermal stability of the

grains is lowered if the grain diameter is made fine and minute and the interaction between the grains is lowered.

[0005]

Further, when a minute recording magnetic domain is formed in the magnetic layer by making the crystal grains in the magnetic layer fine and minute, a problem arises such that the antimagnetic field is increased since the spacing between the magnetic poles of the recording magnetic domain becomes short. Such antimagnetic field causes the inversion of magnetization of the recording magnetic domain formed in the magnetic layer. In order to reduce the effect of such antimagnetic field, it is necessary to decrease the film thickness of the magnetic layer. However, the decrease in film thickness of the magnetic layer results in the decrease in the coercive force thereof, a problem arises such that the magnetic recording domain becomes more unstable due to the thermal fluctuation and so on. Therefore, it is required to enhance the coercive force of the magnetic layer in order to realize high density recording with the magnetic recording medium.

[0006]

The known technique for improving the thermal stability of the magnetic disk includes a method in which a so-called keeper layer having soft magnetization is

provided as an underlying base layer for a recording layer, and a method in which a layer having magnetization in a direction opposite to that of magnetization of a recording layer is provided. As one of the latter method, a technique is disclosed in a literature of E. N. Abarra et al. (E. N. Abarra et al., TECHNICAL REPORT OF IEICE. MR2000-34 (2000-10)) as shown in Fig. 5, in which the thermal stability is improved by forming an Ru thin film to effect a magnetic coupling between a recording layer of CoCrPtB and a magnetization-stabilizing layer of CoCrPtB of a magnetic disk. The literature shows that in the structure of the magnetic disk shown in Fig. 5, when Ru is used as a magnetic coupling layer having a thickness of about 0.5 to 1 nm, the exchange coupling is effected in an antiferromagnetic manner between the recording layer and the magnetization-stabilizing layer. Therefore, in such a magnetic disk, the magnetizations of the recording layer and the magnetization-stabilizing layer are placed in an antiparallel manner from each other, and hence the magnetization of the recording layer is stabilized by the magnetization-stabilizing layer, and the effective volume of inversion of magnetization is increased. Therefore, the magnetic disk is excellent in thermal stability.

[0007]

[PROBLEM TO BE SOLVED BY THE INVENTION]

However, in order to realize further advanced high density recording with a magnetic recording apparatus, it is required to provide a magnetic recording apparatus which is provided with a magnetic disk that is more excellent in thermal stability than the magnetic disk disclosed in the literature described above.

[0008]

A first object of the present invention is to provide a magnetic recording medium which is suitable for high density recording, and a magnetic recording apparatus provided with the same.

[0009]

A second object of the present invention is to provide a magnetic recording medium, especially an in-plane magnetic recording medium which is excellent in thermal stability, and a magnetic recording apparatus provided with the same.

[0010]

A third object of the present invention is to provide a magnetic recording medium in which the coercive force of a recording layer is enhanced.

[0011]

[MEANS FOR SOLVING THE PROBLEM]

According to a first aspect of the present invention, there is provided a magnetic recording medium characterized

by comprising:

an underlying base layer;

a recording layer which is formed of a ferromagnetic material;

a coercive force enhancing layer which exists between the underlying base layer and the recording layer while making contact with the underlying base layer, which is formed of a ferromagnetic material, and which increases a coercive force of the recording layer; and

a non-magnetic layer which exists between the recording layer and the coercive force enhancing layer,

wherein a difference between lattice spacing on an orientation plane of the coercive force enhancing layer and lattice spacing on an orientation plane of the underlying base layer is smaller than a difference between lattice spacing on an orientation plane of the recording layer and the lattice spacing on the orientation plane of the underlying base layer.

[0012]

The magnetic recording medium of the present invention forms the coercive force enhancing layer which is formed of the ferromagnetic material and which is formed between the underlying base layer and the recording layer to make control so that the difference in lattice spacing between the coercive force enhancing layer and the underlying base

layer is smaller than the difference in lattice spacing between the recording layer and the underlying base layer. The coercive force enhancing layer as described above mitigates the lattice strain between the underlying base layer and the recording layer, and the crystalline orientation of the recording layer is improved thereby. Accordingly, it is possible to increase the coercive force of the recording layer. The magnetic recording medium as described above is formed of the ferromagnetic material in the same manner as the magnetization-stabilizing layer of the in-plane magnetic recording medium having the conventional type structure shown in Fig. 5. Therefore, it is possible to stabilize the magnetization of the recording layer. That is, the coercive force enhancing layer has a function to stabilize the magnetization of the recording layer, in addition to a function as a seed layer to act so that the lattice strain between the underlying base layer and the recording layer, i.e., the discrepancy of lattice spacing is mitigated. Therefore, the high density recording can be put into practice by using the magnetic recording medium of the present invention, because the minute magnetic domain formed in the recording layer can be stably retained. In the present invention, the term "lattice spacing" means the lattice spacing on the orientation plane.

[0013]

In the magnetic recording medium according to the present invention, it is preferable that the relationship of $\Delta 1 > \Delta 2$ is satisfied provided that the lattice spacing on the orientation plane of the recording layer is defined as a_1, the lattice spacing of the coercive force enhancing layer is defined as a_2, the lattice spacing of the underlying base layer is defined as a_3, and the mismatch $\Delta 1$ in lattice spacing between the recording layer and the underlying base layer and the mismatch $\Delta 2$ in lattice spacing between the coercive force enhancing layer and the underlying base layer are defined by the following expression:

$$\Delta i = |(a_i - a_3)/a_3| \times 100 \text{ (i is 1 or 2)} \qquad \cdots (1)$$

provided that the symbol "| |" indicates the absolute value in the expression (1). In general, the mismatch in lattice spacing results from the difference in lattice spacing at the interface between the respective layers of the stack obtained by growing and stacking a plurality of layers. The recording layer is grown from the top of the coercive force enhancing layer via the non-magnetic layer. Therefore, the orientation of the recording layer depends on the difference in lattice spacing between the recording layer and the coercive force enhancing layer. On the other hand, the orientation of the coercive force enhancing layer

depends on the difference in lattice spacing between the coercive force enhancing layer and the underlying base layer. As described above, the mismatch Δ2 in lattice spacing between the coercive force enhancing layer and the underlying base layer is made smaller than the mismatch Δ1 in lattice spacing between the recording layer and the underlying base layer. Accordingly, it is possible to allow the coercive force enhancing layer to function as a seed layer for the recording layer, and it is possible to grow the recording layer from the underlying base layer in a desired orientation.

[0014]

In order to further enhance the lattice match between the underlying base layer and the recording layer, it is desirable to reduce the mismatch in lattice spacing between the coercive force enhancing layer and the recording layer and the mismatch in lattice spacing between the recording layer and the underlying base layer to be within 5 % respectively. For this purpose, it is preferable that the mismatches Δ1, Δ2 simultaneously satisfy the relationships of $\Delta 2 < \Delta 1 < 10.25$ and $(5/10.25) < \Delta 2/\Delta 1 < 1$. When the value of $\Delta 2/\Delta 1$ is within the range as described above, if any lattice strain exists between the underlying base layer and the recording layer, then the lattice strain can be effectively mitigated by the coercive force enhancing

layer. Thus, the recording layer having the desired lattice spacing can be formed from the top of the underlying base layer via the coercive force enhancing layer. Accordingly, it is possible to further increase the coercive force of the recording layer.

[0015]

In the present invention, it is ideal that the coercive force enhancing layer has the same crystal structure as that of the recording layer, because it is necessary to control and orient the easy axis of magnetization of the recording layer in the in-plane direction. In the case of the magnetic recording medium based on the in-plane recording system, when the exchange coupling is effected between the coercive force enhancing layer and the recording layer, the magnetic anisotropy energy is lowest if the magnetization of the coercive force enhancing layer is parallel to the magnetization of the recording layer, and the stability of the magnetization is in the best state.

[0016]

It is desirable for the magnetic recording medium of the present invention that a relationship of $Ms1 > Ms2$ is satisfied provided that saturation magnetization of the coercive force enhancing layer is represented by Ms1, and saturation magnetization of the recording layer is

represented by Ms2. For this purpose, it is desirable that the coercive force enhancing layer is formed so that a ratio of magnetic element contained in the coercive force enhancing layer is larger than a ratio of magnetic element contained in the recording layer. Accordingly, it is possible to further increase the exchange coupling force between the recording layer and the coercive force enhancing layer. In the case of the conventional type medium shown in Fig. 5, the recording layer and the magnetization-stabilizing layer are composed of the same material, in which the composition and the crystal structure are also the same. The recording layer and the magnetization-stabilizing layer are subjected to exchange coupling via the Ru layer. It is considered that the exchange coupling is based on the fact that the electron orbits are coupled to one another for the Co atoms in the recording layer and the magnetization-stabilizing layer by the aid of the Ru atoms. In the present invention, the ratio of the magnetic element in the coercive force enhancing layer is made higher than the ratio of the magnetic element in the recording layer to increase the amount of magnetic element which contributes to the exchange coupling. Therefore, the exchange coupling force between the recording layer and the coercive force enhancing layer is increased as compared with the exchange

coupling force between the recording layer and the magnetization-stabilizing layer of the conventional type medium shown in Fig. 5. Accordingly, it is possible to improve the thermal stability as compared with the conventional type medium shown in Fig. 5.

[0017]

The coercive force enhancing layer may be formed of, for example, an alloy containing Co, Ni, or Fe. Alternatively, the coercive force enhancing layer may be formed of an alloy containing Co, Ni, or Fe and a transition metal, especially a noble metal such as Pt, Au, Ag, Cu, and Pd. The element or the alloy as described above functions to electronically make coupling by the aid of the non-magnetic layer and increase the exchange coupling magnetic field.

[0018]

In the present invention, the coercive force of the recording layer and the exchange coupling force between the recording layer and the coercive force enhancing layer can be controlled by adjusting the film thickness and the material to be used for the coercive force enhancing layer. As shown in Fig. 3, the following tendency exists. That is, when the film thickness of the coercive force enhancing layer is thick, the coercive force of the recording layer is increased. When the film thickness is thin, the

exchange coupling force between the recording layer and the coercive force enhancing layer is increased. Therefore, it is possible to appropriately select the film thickness depending on which characteristic has priority. According to experimental results having been obtained until now, it has been revealed that the exchange coupling between the coercive force enhancing layer and the recording layer does not exhibit anti-ferromagnetic exchange coupling in some cases, if the film thickness of the coercive force enhancing layer exceeds 9.0 nm. On the other hand, it has been revealed that the lattice match between the coercive force enhancing layer and the recording layer formed thereon is maintained, and it is possible to sufficiently increase the coercive force of the recording layer, if the film thickness of the coercive force enhancing layer is not less than 1.0 nm. Accordingly, in order to increase both of the coercive force of the recording layer and the exchange coupling force between the recording layer and the coercive force enhancing layer in a well-balanced manner, it is preferable that the film thickness of the coercive force enhancing layer is 1.0 nm to 9.0 nm.

[0019]

In the magnetic recording media of the present invention, the non-magnetic layer may be formed of Ru. However, there is no limitation thereto. It is possible to

use a transition metal such as Rh, Ir, Hf, Cu, Cr, Ag, Au, Re, Mo, Nb, W, Ta, and V, and a non-magnetic alloy based on the CoCr system such as CoCrRu. Ru is preferred in order to further enhance the exchange coupling. In the present invention, the non-magnetic layer has a function to magnetically couple the recording layer and the coercive force enhancing layer. Therefore, the non-magnetic layer is also referred to as "magnetic coupling layer".

[0020]

In the magnetic recording medium of the present invention, the recording layer may be crystalline, and the crystalline phase may be composed of an alloy principally containing cobalt (Co). The Co alloy may contain Co as well as Cr, Pt, Ta, Nb, Ti, Si, B, P, Pd, V, Tb, Gd, Sm, Nd, Dy, Ho or Eu, or a combination thereof.

[0021]

When the recording layer contains chromium (Cr), it is possible to form a segregation portion of Cr at the grain boundary or in the vicinity of the grain boundary between the crystal grains (magnetic grains) principally containing Co. When the recording layer further contains Ta, Nb, Ti, B, P, or a combination of these elements, the segregation of Cr is facilitated. Owing to the segregation, it is possible to reduce the magnetic interaction between the magnetic grains, and it is possible to decrease the number

of magnetic grains for constructing the unit of inversion of magnetization. Therefore, it is possible to provide the magnetic recording medium which is strong against the thermal fluctuation regardless of the minute unit of inversion of magnetization, when the coercive force enhancing layer of the present invention is used in combination with the recording layer containing the foregoing additive in the CoCr alloy. In the recording layer as described above, the magnetic coupling between the crystal grains is broken by the Cr-rich non-magnetic area segregated at the grain boundary. Therefore, the noise, which would otherwise result from the recording transition area, can be also suppressed.

[0022]

In the magnetic recording medium of the present invention, the underlying base layer may be formed of, for example, Cr or Ni, or, Cr alloy or Ni alloy. The Cr alloy or the Ni alloy may contain Cr, Ti, Ta, V, Ru, W, Mo, Nb, Ni, Zr, or Al other than the base element. The underlying base layer is used in order to control the crystalline orientation and the lattice spacing of the recording layer. The underlying base layer may be also used as a single layer or a plurality of layers.

[0023]

The magnetic recording medium of the present invention

may further comprise a substrate. In this arrangement, the underlying base layer is formed on the substrate. The substrate may be formed of glass or plastic such as polycarbonate.

[0024]

According to a second aspect of the present invention, there is provided a magnetic recording medium comprising:

a recording layer which is formed of a ferromagnetic material;

a coercive force enhancing layer is formed of a ferromagnetic material and which increases a coercive force of the recording layer; and

a non-magnetic layer which exists between the recording layer and the coercive force enhancing layer.

[0025]

In the magnetic recording medium according to the second aspect of the present invention, the coercive force of the recording layer can be increased owing to the coercive force enhancing layer as compared with a case in which the recording layer is formed as a single layer. Accordingly, information can be recorded at a high density on the recording layer. Further, the thermal stability of recorded information is excellent. Further, the exchange coupling force is exerted between the coercive force

enhancing layer and the recording layer via the non-magnetic layer, because the coercive force enhancing layer is formed of the ferromagnetic material. Therefore, the coercive force enhancing layer also functions to stabilize the magnetization of the recording layer. In order to increase the coercive force of the recording layer, it is desirable to reduce the mismatch in lattice spacing between the coercive force enhancing layer and the recording layer. In order to reduce the mismatch in lattice spacing between the coercive force enhancing layer and the recording layer, for example, the underlying base layer may be provided. The underlying base layer is positioned in the medium such that the coercive force enhancing layer is positioned between the underlying base layer and the recording layer. Here, it is desirable that the underlying base layer controls the orientation of the recording layer and has a structure similar to the crystal structure of the recording layer with which a high coercive force can be obtained. In order to increase the coercive force of the recording layer, the crystal grain diameter of the coercive force enhancing layer may be controlled.

[0026]

The magnetic recording medium as described above has a magnetic characteristic which is represented by a hysteresis loop as depicted by a magnetization curve as

shown in Fig. 4. In the hysteresis loop shown in Fig. 4, a point, at which a rate of change of magnetization with respect to the external magnetic field exhibits a local maximum when the external magnetic field is lowered after magnetization of the magnetic recording medium is saturated, exists in an area of positive magnetic field. When the magnetization of the magnetic recording medium is saturated, both of the magnetizations of the recording layer and the coercive force enhancing layer are parallel. The magnetization of the coercive force enhancing layer is inverted due to the exchange coupling force exerted between the coercive force enhancing layer and the recording layer in the area in which the rate of change of magnetization exhibits the local maximum as the external magnetic field is lowered. In the residual magnetization state, the thermal stability of the magnetization of the recording layer is improved owing to the exchange coupling force as described above. Further, a minor hysteresis loop as shown in Fig. 4 may be observed in the area in which the rate of change of magnetization is locally maximized. The exchange coupling magnetic field H_{ex}, which is determined from the central point of the minor hysteresis loop, is increased in accordance with the increase of the exchange coupling force between the coercive force enhancing layer and the recording layer. Therefore, it is indicated that the

larger the exchange coupling magnetic field is, the larger the thermal stability is. The exchange coupling magnetic field H_{ex} is not less than 1 kOe, preferably not less than 1.5 kOe, which is remarkably larger than that of the conventional type magnetic recording medium shown in Fig. 5. Therefore, it is appreciated that the magnetic recording medium of the present invention is excellent in thermal stability.

[0027]

In order to generate the large exchange coupling magnetic field H_{ex}, for example, it is desirable that the coercive force enhancing layer is formed so that the ratio of the magnetic element contained in the coercive force enhancing layer is larger than the ratio of the magnetic element contained in the recording layer.

[0028]

According to a third aspect of the present invention, there is provided a magnetic recording apparatus comprising:

the magnetic recording medium according to the first or the second aspect of the present invention;

a magnetic head which is used to record or reproduce information on the magnetic recording medium; and

a driving unit which drives the magnetic recording medium with respect to the magnetic head.

[0029]

The magnetic recording apparatus according to the present invention is excellent in recording stability over a long period of time, because the magnetic recording apparatus is installed with the magnetic recording medium which is excellent in thermal stability.

[0030]

[EMBODIMENT OF THE INVENTION]

The magnetic recording medium and the magnetic recording apparatus according to the present invention will be specifically explained below in accordance with embodiments and Comparative Examples. However, the present invention is not limited to the embodiments.

[0031]

[FIRST EMBODIMENT]

Fig. 1 shows a sectional view of a typical embodiment of the magnetic recording medium according to the present invention. A magnetic recording medium comprises, on a glass substrate 20, a first underlying base layer 2, a second underlying base layer 4, a coercive force enhancing layer 6, a magnetic coupling layer 8, a recording layer 12, and a protective layer 14. The respective layers were formed as follows by means of sputtering by using a DC magnetron sputtering apparatus.

[0032]

An NiAl film was formed as the first metal underlying base layer 2 on the glass substrate 20 having a diameter of 2.5 inches (6.25 cm) by means of sputtering by using the DC magnetron sputtering apparatus. An NiAl alloy having an atomic ratio of Ni:Al = 50:50 was used for a target. The NiAl film had a film thickness of 50 nm. The Ar gas pressure during the sputtering was 0.3 Pa, and the introduced electric power was 0.5 kW. The substrate was heated to 340 °C after the pressure of the sputtering chamber was reduced to be not more than 1×10^{-5} Pa before starting the sputtering. The speed of film formation was about 3 nm/second under this condition.

[0033]

A CrMo film was formed as the second metal underlying base layer 4 to have a film thickness of 20 nm on the first metal underlying base layer 2. A CrMo alloy containing Mo by 27 atomic % was used for a target. The film formation condition was the same as that for the first metal underlying base layer 2.

[0034]

A CoPt film was formed as the coercive force enhancing layer 6 to have a film thickness of 2 nm on the second metal underlying base layer 4. A CoPt alloy containing Pt by 17 atomic % was used for a target. The film formation condition was the same as that for the first metal

underlying base layer 2.

[0035]

Subsequently, an Ru film was formed as the magnetic coupling layer 8 to have a film thickness of 0.8 nm on the coercive force enhancing layer 6. Ru was used for a target. The film formation condition during the sputtering was the same as that for the first enhancing layer 8.

[0036]

A CoCrPtB film having magnetization in the in-plane direction was formed as the recording layer 10 to have a film thickness of 18 nm on the magnetic coupling layer 8. A $Co_{64}Cr_{20}Pt_{12}B_4$ alloy was used for a target. The film formation condition was the same as that for the coercive force enhancing layer 6.

[0037]

Finally, a carbon layer was formed as a protective film to have a film thickness of 5 nm on the CoCrPtB recording layer 12. The film formation condition was the same as that for the first metal underlying base layer 2. Thus, the magnetic disk 10 having the structure shown in Fig. 1 was produced.

[0038]

[COMPARATIVE EXAMPLE 1]

As Comparative Example, a CoCrPtB film having the same composition as that of the recording layer 10 was formed in

place of the coercive force enhancing layer 6. The coercive force enhancing laye had a film thickness of 4.5 nm, and the recording layer had a film thickness of 18 nm, in the same manner of the recording layer of the first embodiment.

[0039]

[EVALUATION OF MAGNETIZATION CURVE]

The magnetization was measured as follows for the magnetic disk manufactured in the first embodiment. The magnetic field was applied with VSM (Vibration Sample Magnetometer) to observe the magnetization curve with respect to the external magnetic field. An obtained result is shown in Fig. 2. As appreciated from a hysteresis loop shown in Fig. 2, an area exists, in which the magnetization is suddenly lowered at a certain magnetic field before the external magnetic field is zero when the external magnetic field is lowered after the external magnetic field in the positive direction is applied to saturate the magnetization. This phenomenon is caused by the influence of the exchange coupling exerted between the recording layer and the coercive force enhancing layer. This phenomenon appears as follows. That is, when the magnetization of the magnetic recording medium is saturated, the magnetization of the recording layer is parallel to the magnetization of the coercive force

enhancing layer. However, when the external magnetic field is lowered, then the magnetization of the coercive force enhancing layer is inverted to be antiparallel to the direction of magnetization of the recording layer, thereby causing this phenomenon.

[0040]

The coercive force of the recording layer was determined from the hysteresis loop shown in Fig. 2. The way of determining the coercive force will be explained below. The hysteresis loop shown in Fig. 2 is the hysteresis loop of the magnetic recording medium. The value of magnetization on the hysteresis loop indicates the sum of magnetizations of the recording layer and the coercive force enhancing layer constructed with the magnetic materials respectively. On the other hand, the coercive force of the recording layer is usually defined by the magnitude of the external magnetic field to be obtained when the magnitude of magnetization of the recording layer is zero in the hysteresis loop depicted by only the magnetization of the recording layer. Accordingly, the coercive force of the recording layer was estimated as follows from the hysteresis loop shown in Fig. 2. As for the hysteresis loop shown in Fig. 2, it is assumed that only the magnetization of the coercive force enhancing layer is detected when the magnetization of the recording

layer is zero. It is assumed that the magnitude of the magnetization of the coercive force enhancing layer in this case is M_{sta}. On this assumption, the magnitude of the external magnetic field, at which the magnetization of $-M_{sta}$ is obtained in the hysteresis loop shown in Fig. 2, indicates the external magnetic field to be obtained when the magnetization of the recording layer is zero, i.e., the coercive force of the recording layer. M_{sta} can be estimated as follows from the hysteresis loop shown in Fig. 2.

[0041]

As described above, in the hysteresis loop shown in Fig. 2, the magnetization is suddenly decreased between Point A and Point B on the loop as shown in Fig. 2, when the external magnetic field is lowered after the external magnetic field in the positive direction is applied to saturate the magnetization. The sudden decrease in magnetization between Point A and Point B is caused such that only the magnetization of the coercive force enhancing layer is inverted without any change of the direction of magnetization of the recording layer. The direction of magnetization of the recording layer is parallel to that of the coercive force enhancing layer at Point A on the loop. The magnetization at Point A represents the sum of magnetizations of the recording layer and the coercive

force enhancing layer. On the other hand, the directions of magnetization of the respective layers are antiparallel at Point B. Accordingly, the magnetization at Point B represents the difference in magnetization between the recording layer and the coercive force enhancing layer. Therefore, the magnetization M_{sta} of the coercive force enhancing layer described above can be estimated as a half of the difference between the value of magnetization at Point A and the value of magnetization at Point B on the loop.

[0042]

The coercive force of the recording layer was determined from the hysteresis loop shown in Fig. 2 in accordance with the method as described above. As a result, the coercive force was about 4.5 kOe. On the other hand, the coercive force was determined in accordance with the same method for the recording layer of the magnetic disk of Comparative Example. As a result, the coercive force of the recording layer was about 3.5 kOe. That is, the coercive force of the recording layer of the magnetic disk of this embodiment was increased by about 30 % as compared with the recording layer of the magnetic disk of Comparative Example.

[0043]

The relation of orientation between the second

underlying base layer 4 and the recording layer 10 resides in CrMo(211)[110]//CoCrPtB(10•0)[0001]. The lattice spacing of CrMo[110] as the second underlying base layer 4 is 4.182 angstroms, the lattice spacing of [0001] of CoPt used as the coercive force enhancing layer 6 in this embodiment is 4.178 angstroms, and the lattice spacing of CoCrPtB used as the recording layer 10 is 4.159 angstroms. When the mismatch $\Delta 1$ in lattice spacing between the recording layer 10 and the second underlying base layer 4, and the mismatch $\Delta 2$ in lattice spacing between the coercive force enhancing layer 6 and the second underlying base layer 4 are determined from the expression (1) described above, there are given $\Delta 1 = 0.550$ % and $\Delta 2 = 0.096$ %, in which $\Delta 1 > \Delta 2$ is satisfied. On the other hand, in the case of the magnetic disk of Comparative Example, both of the recording layer and the coercive force enhancing layer are composed of CoCrPtB having the same composition, in which there is given for the mismatch $\Delta 1 = \Delta 2 = 0.550$ %. Therefore, when the coercive force enhancing layer is formed as the film on CrMo as the second underlying base layer, the mismatch in lattice spacing between the underlying base layer and the recording layer can be decreased when CoPt is used for the coercive force enhancing layer as compared with the case in which CoCrPtB is used. Therefore, it is possible to improve the

crystallinity of the recording layer.

[0044]

In the hysteresis loop shown in Fig. 2, in the area in which the magnetization is suddenly lowered before the magnetic field is zero, a point appears, at which the rate of change of magnetization with respect to the external magnetic field (δM/δH) is locally maximized. When the magnetic field is lowered after the appearance of the local maximum point, and the external magnetic field is increased again after the rate of change of the magnetization is stabilized, then a hysteresis curve is obtained as depicted with hatched area in Fig. 4. The hysteresis curve is called "minor loop". The magnetic field H, which is located at the center of the loop disposed at the midpoint between the upper end and the lower end of the minor loop, is known as the exchange coupling magnetic field Hex which is proportional to the exchange coupling between the recording layer 10 and the coercive force enhancing layer 6. In the case of the magnetic disk obtained in this embodiment, it has been revealed that Hex is about 1.0 kOe. On the other hand, in the case of the magnetic disk of Comparative Example, it has been revealed that Hex determined from a minor loop is 0.4 kOe. Therefore, in the present invention, the exchange coupling force between the coercive force enhancing layer and the recording layer is

increased by increasing the ratio of the magnetic element in the coercive force enhancing layer as compared with the recording layer.

[0045]

Next, as for the magnetic disks of the first embodiment of the present invention and Comparative Example, the value $Ku \cdot V/k_B \cdot T$ (Ku represents the crystalline magnetic anisotropy constant of the recording layer, V represents the volume of activation, k_B represents the Boltzmann's constant, and T represents the absolute temperature) was determined as the index for the thermal stability of the magnetic disk. As a result, the value was about 78 in the case of the magnetic disk of the first embodiment of the present invention. On the other hand, the value was about 65 in the case of the magnetic recording medium of Comparative Example. Also according to this fact, it is understood that the magnetic recording medium of the present invention is excellent in thermal stability. Further, in the case of the magnetic disk of the embodiment of the present invention, Brt as the index to exhibit the possibility of high density recording on the in-plane magnetic recording medium was about 49.7 Gμm.

[0046]

Next, magnetic disks were produced in accordance with the same process as that of the first embodiment except

that coercive force enhancing layers were formed with various film thicknesses to obtain a plurality of magnetic disks having different film thicknesses of the coercive force enhancing layers. The magnetization curve was observed to determine the coercive force of the recording layer by means of VSM in the same manner as described above for each of the magnetic disks. Fig. 3 shows a relationship between the film thickness of the CoPt layer as the coercive force enhancing layer and the coercive force of the recording layer. As appreciated from this result, the coercive force of the recording layer is increased as the film thickness of the CoPt film is increased.

[0047]

Subsequently, the exchange coupling magnetic field was determined in accordance with the same method as described above to determine the dependency of the exchange coupling magnetic field with respect to the film thickness of the coercive force enhancing layer for the respective magnetic disks in which the film thickness of the coercive force enhancing layer differed. An obtained result is shown in a graph in Fig. 3. As understood from this graph, the exchange coupling magnetic field is decreased, as the film thickness of the coercive force enhancing layer is increased. According to Fig. 3, it is understood that when

the coercive force enhancing layer is formed of the CoPt layer, the optimum film thickness of the coercive force enhancing layer, which makes it possible to increase both of the exchange coupling magnetic field and the coercive force of the recording layer in a well-balanced manner, is 1.0 nm to 2.0 nm.

[0048]

[SECOND EMBODIMENT]

A plurality of magnetic disks were produced in accordance with the same process as that used in the first embodiment. A lubricant was applied onto the protective layers of the respective disks, and then the disks were coaxially attached to a spindle of a magnetic recording apparatus. A schematic arrangement of the magnetic recording apparatus is shown in Figs. 6 and 7. Fig. 6 shows a top view of the magnetic recording apparatus, and Fig. 7 shows a cross-sectional view of the magnetic recording apparatus 60 taken along a broken line A-A' shown in Fig. 6. A dual spin bulb-type magnetic head, which has a high saturation magnetic flux density of 2.1 T, was used as a recording magnetic head. The recording magnetic head and the reproducing magnetic head were integrated into one unit, and they are indicated as a magnetic head 53 in Figs. 6 and 7. The integrated type magnetic head 53 is controlled by a magnetic head-driving system 54. The

plurality of magnetic disks 10 are coaxially rotated by the spindle 52 of a rotary driving system 51. The distance between the magnetic disk and the magnetic head surface of the magnetic recording apparatus was maintained to be 11 nm. A signal corresponding to 40 Gbits/inch^2 (6.20 Gbits/cm^2) was recorded on the magnetic disk to evaluate S/N of the magnetic disk. As a result, a reproduction output of 25 dB was obtained.

[0049]

In order to evaluate the recording stability of the magnetic recording apparatus 60, the magnetic recording apparatus 60 was placed in an environment at 80 °C at a humidity of 80 % for 100 hours. After the passage of 100 hours, the recorded signal was reproduced to measure S/N of the magnetic disk. As a result, a reproduction output of 24.3 dB was obtained. That is, the rate of decrease of the recording signal in the environment described above was 3 %.

[0050]

[COMPARATIVE EXAMPLE 2]

The magnetic disk 50 of Comparative Example 1 was incorporated into the magnetic recording apparatus in the same manner as in the second embodiment. In order to evaluate the recording stability of the magnetic recording apparatus, the magnetic recording apparatus 60 was placed

in an environment at 80 °C at a humidity of 80 % for 100 hours. After the passage of 100 hours, the recorded signal was reproduced to measure S/N of the magnetic disk. As a result, a reproduction output of 22.5 dB was obtained. That is, the rate of decrease of the recording signal in the environment described above was 10 %. Therefore, it is appreciated that the magnetic recording apparatus provided with the magnetic disk of the present invention is excellent in recording stability.

[0051]

In the foregoing, the present invention has been specifically explained with reference to the embodiments. However, the present invention is not limited thereto. The first metal underlying base layer, the second metal underlying base layer, the coercive force enhancing layer, the magnetic coupling layer and the recording layer may be constructed with a variety of known materials without being limited to the materials described in the embodiments.

[0052]

[EFFECTS OF THE INVENTION]

In the magnetic recording medium of the present invention, the crystalline orientation of the recording layer is improved owing to the coercive force enhancing layer having the lattice spacing so that the mismatch in lattice spacing between the underlying base layer and the

recording layer is mitigated. Therefore, the coercive force of the recording layer is increased. Accordingly, minute magnetic domains can be formed in the recording layer, and it is possible to realize further advanced high density recording. Further, the exchange coupling force between the coercive force enhancing layer and the recording layer can be increased by increasing the ratio of the magnetic element in the coercive force enhancing layer as compared with the recording layer. The magnetic recording medium as described above is excellent in thermal stability, and it has the high coercive force. Therefore, it is possible to perform the super high density recording on the magnetic recording medium. Accordingly, the magnetic recording apparatus, which is provided with the magnetic recording medium of the present invention, is excellent in recording stability. It is possible to realize the super high density recording exceeding, for example, 40 Gbits/inch^2.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1] Fig. 1 shows a cross-sectional structure of a magnetic disk according to a first embodiment.

[Fig. 2] Fig. 2 shows a graph illustrating a hysteresis loop (major loop) of the magnetic disk according to the first embodiment.

[Fig. 3] Fig. 3 shows a graph illustrating a

relationship between a film thickness of a coercive force enhancing layer and a coercive force of a recording layer and a relationship between the film thickness of the coercive force enhancing layer and an exchange coupling magnetic field.

[Fig. 4] Fig. 4 shows a sectional view illustrating a structure of a conventional magnetic disk.

[Fig. 5] Fig. 5 schematically shows a minor loop of the hysteresis loop shown in Fig. 2.

[Fig. 6] Fig. 6 shows a schematic arrangement of a magnetic recording apparatus according to a second embodiment of the present invention as viewed from a position thereover.

[Fig. 7] Fig. 7 shows a sectional view as viewed in a direction of A-A' illustrating the magnetic recording apparatus shown in Fig. 6.

[EXPLANATION OF REFERENCE NUMERALS]

2	first metal underlying base layer
4	second metal underlying base layer
6	coercive force enhancing layer
8	magnetic coupling layer
10	magnetic disk
12	recording layer
14	protective layer
20	substrate

52 spindle

53 magnetic head

60 magnetic recording apparatus

Patent Application No. 2001-078630

[TITLE OF THE DOCUMENT] Abstract

[ABSTRACT]

[PROBLEMS] To provide a magnetic recording medium for high-density recording which is excellent in thermal stability.

[MEANS TO SOLVE PROBLEMS] An in-plane magnetic recording medium 10 has, on a substrate 20, a first underlying base layer 2 of NiAl, a second underlying base layer 4 of CrMo, a coercive force enhancing layer 6 of CoPt, a magnetic coupling layer 8 of Ru, a recording layer 12 of CoCrPtB, and a protective layer 14 of carbon. The difference in lattice spacing between the coercive force enhancing layer 6 and the second underlying base layer 4 is made to be smaller than the difference in lattice spacing between the recording layer 12 and the second underlying base layer 4, and the crystallinity of the recording layer 12 is improved thereby. Further, the coercive force enhancing layer 6 is formed by using a material which contains the magnetic element at a concentration which is greater than that of the recording layer 12, thereby enhancing the coupling force between the coercive force enhancing layer 6 and the recording layer 12. Accordingly, it is possible to provide a magnetic recording apparatus which is excellent in recording stability over a long period of time in which the thermal stability of the

magnetic recording medium is excellent.

[SELECTED DRAWINGS] Fig. 1

[TITLE OF THE DOCUMENT] Drawing

Fig. 1

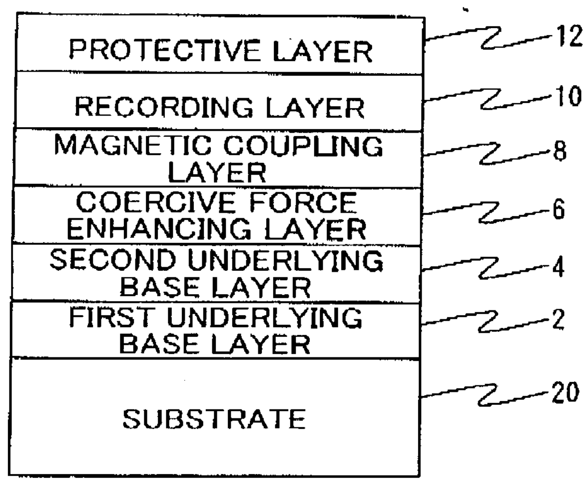


Fig. 2

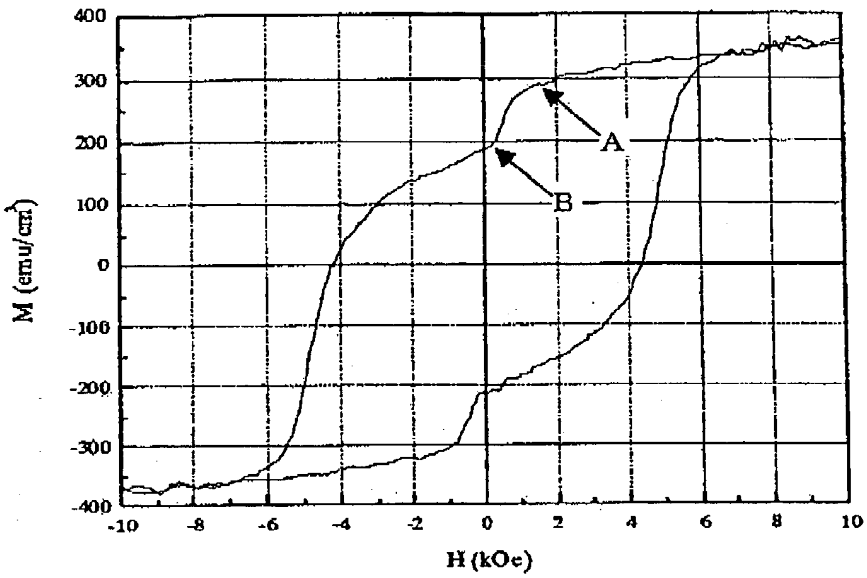
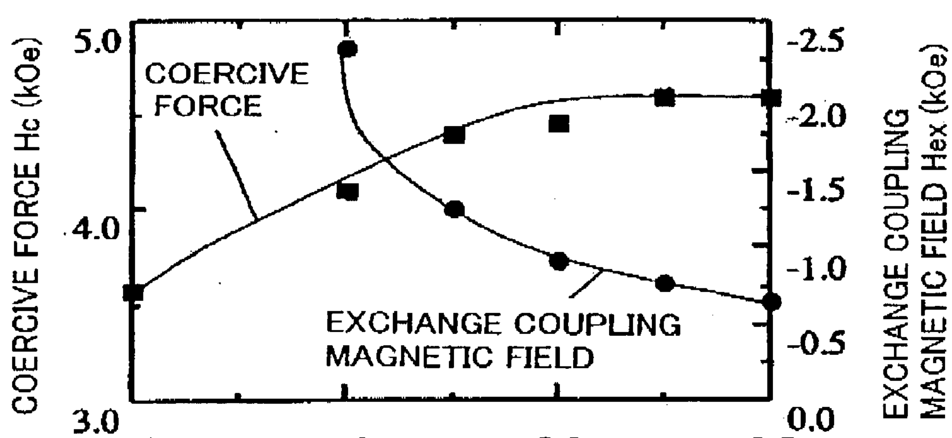


Fig. 3



FILM THICKNESS OF COERCIVE FORCE
ENHANCING LAYER of CoPt (nm)

Fig. 4

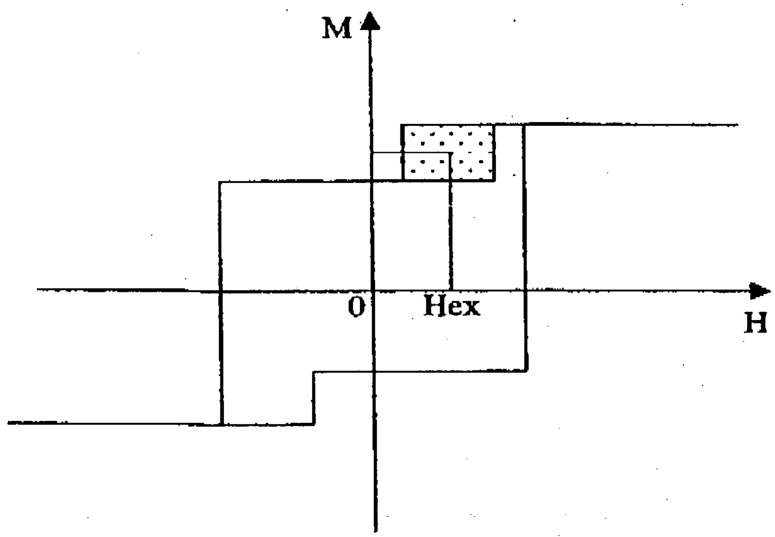


Fig. 5

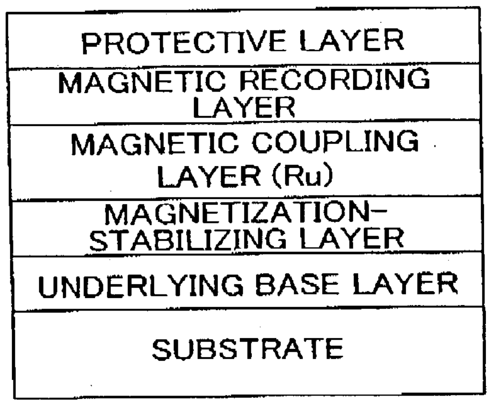

PROTECTIVE LAYER
MAGNETIC RECORDING LAYER
MAGNETIC COUPLING LAYER (Ru)
MAGNETIZATION-STABILIZING LAYER
UNDERLYING BASE LAYER
SUBSTRATE

Fig. 6

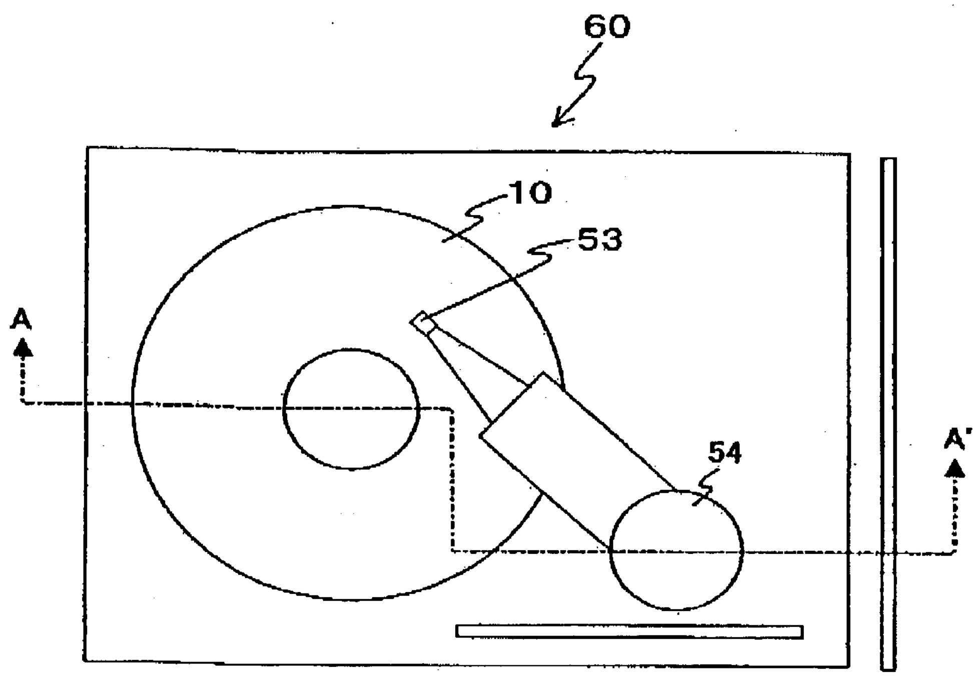
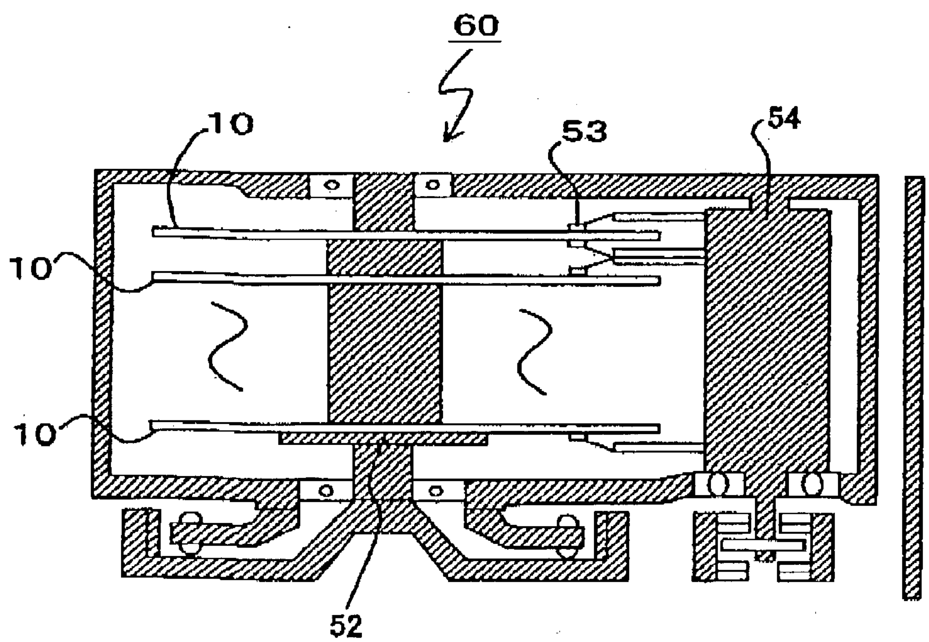


Fig. 7



TRANSLATOR'S VERIFICATION

I hereby declare and state that I am knowledgeable of each of the Japanese and English languages and that I made and reviewed the attached translation of the certified copy of Japanese Patent Application No. 2000-359200, filed on November 27, 2000 from the Japanese language into the English language, and that I believe my attached translation to be accurate, true and correct to the best of my knowledge and ability.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of this application or any patent issued thereon.

Date: February 3, 2004

Kiyoko Ishimura
(Signature)

Kiyoko Ishimura
(Typed name)

JAPAN PATENT OFFICE

This is to certify that the annexed is a true copy of the following application as filed with this Office.

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Applicant(s):	HITACHI MAXELL, LTD.

September 14, 2001
Commissioner, Japan Patent Office
Kozo OIKAWA

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[Name of Document] Drawing 1

[Name of Document] Abstract 1

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INFORMATION ON APPLICANT'S HISTORY

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Patent Application No. 2000-359200

[TITLE OF THE DOCUMENT] Specification

[TITLE OF THE INVENTION] MAGNETIC RECORDING MEDIUM AND MAGNETIC RECORDING APPARATUS

[CLAIMS]

[Claim 1] A magnetic recording medium comprising:

a recording layer which is formed of a ferromagnetic material;

a magnetization-stabilizing layer which is formed of a ferromagnetic material and which stabilizes magnetization of the recording layer;

a non-magnetic layer which exists between the recording layer and the magnetization-stabilizing layer; and

an enhancing layer which exists at least one of positions between the non-magnetic layer and the recording layer and between the non-magnetic layer and the magnetization-stabilizing layer, and which increases exchange coupling between the recording layer and the magnetization-stabilizing layer.

[Claim 2] The information-recording medium according to claim 1, characterized in that the enhancing layer is formed of one selected from the group consisting of Co, Ni, Fe, and CoNiFe alloy.

[Claim 3] The information-recording medium according to claim 1, characterized in that the enhancing layer is

formed of an alloy containing a transition metal and Co, Ni or Fe.

[Claim 4] The magnetic recording medium according to claim 1, characterized in that:

the recording layer or the magnetization-stabilizing layer is formed of a material containing Co, Ni or Fe; and

the enhancing layer is formed of a material containing Co, Ni or Fe at a concentration which is higher than a concentration in the recording layer or the magnetization-stabilizing layer.

[Claim 5] The magnetic recording medium according to any one of claims 1 to 4, characterized in that the enhancing layer includes a first enhancing layer which exists between the non-magnetic layer and the magnetization-stabilizing layer and a second enhancing layer which exists between the non-magnetic layer and the recording layer.

[Claim 6] The magnetic recording medium according to any one of claims 1 to 5, characterized in that the enhancing layer has a film thickness of 0.5 to 3 nm.

[Claim 7] The magnetic recording medium according to any one of claims 1 to 6, characterized in that the non-magnetic layer is formed of Ru.

[Claim 8] The magnetic recording medium according to any one of claims 1 to 7, characterized in that:

the magnetization-stabilizing layer includes a first magnetization-stabilizing layer and a second magnetization-stabilizing layer, and the non-magnetic layer includes a first non-magnetic layer and a second non-magnetic layer, the first non-magnetic layer being formed between the first magnetization-stabilizing layer and the second magnetization-stabilizing layer, and the second non-magnetic layer being formed between the second magnetization-stabilizing layer and the recording layer; and

the enhancing layer is provided at least at one of positions between the second non-magnetic layer and the recording layer and between the second non-magnetic layer and the second magnetization-stabilizing layer, and comprises an auxiliary enhancing layer which is provided at least at one of positions between the first magnetization-stabilizing layer and the first non-magnetic layer and between the first non-magnetic layer and the second magnetization-stabilizing layer, and which increases exchange coupling between the first magnetization-stabilizing layer and the second magnetization-stabilizing layer.

[Claim 9] The magnetic recording medium according to claim 8, characterized in that the auxiliary enhancing layer includes a first auxiliary enhancing layer which is

formed between the first non-magnetic layer and the first magnetization-stabilizing layer, and a second auxiliary enhancing layer which is formed between the first non-magnetic layer and the second magnetization-stabilizing layer.

[Claim 10] The magnetic recording medium according to any one of claims 1 to 9, characterized by further comprising a substrate on which an underlying base layer is formed, wherein the magnetization-stabilizing layer is provided on the underlying base layer.

[Claim 11] A magnetic recording medium characterized by comprising:

a recording layer which is formed of a ferromagnetic material;

a magnetization-stabilizing layer which is formed of a ferromagnetic material and which stabilizes magnetization of the recording layer; and

a non-magnetic layer which exists between the recording layer and the magnetization-stabilizing layer,

wherein a magnetization curve of the magnetic recording medium with respect to an external magnetic field exhibits a hysteresis loop, a point, at which a rate of change of magnetization with respect to the external magnetic field exhibits a local maximum when the external magnetic field is lowered after magnetization is saturated,

exists in a positive area of the external magnetic field, and an exchange coupling magnetic field, which is determined from the magnetization curve, is not less than 1 kOe.

[Claim 12] The magnetic recording medium according to claim 11, characterized by further including an enhancing layer which exists at least one of positions between the non-magnetic layer and the recording layer and between the non-magnetic layer and the magnetization-stabilizing layer, and which increases exchange coupling between the recording layer and the magnetization-stabilizing layer.

[Claim 13] The magnetic recording medium according to claim 11 or 12, characterized in that the recording layer and the magnetization-stabilizing layer include Co, Ni or Fe, and the enhancing layer is formed of Co, Ni or Fe.

[Claim 14] The magnetic recording medium according to claim 1 or 11, characterized in that the recording layer has a magnetization in the in-plane direction.

[Claim 15] A magnetic recording apparatus comprising:

the magnetic recording medium according to claim 1 or 11;

a magnetic head which is used to record or reproduce information on the magnetic recording medium; and

a driving unit which drives the magnetic recording medium with respect to the magnetic head.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[TECHNICAL FIELD TO WHICH THE INVENTION BELONGS]

The present invention relates to a magnetic recording medium and a magnetic recording apparatus. In particular, the present invention relates to an in-plane magnetic recording medium which is excellent in thermal stability and which is preferable for high density recording, and a magnetic recording apparatus which is installed with the in-plane magnetic recording medium.

[0002]

[PRIOR ART]

Accompanying with the recent progress of the advanced information society, the multimedia, with which not only the character information but also the voice and image information can be processed at a high speed, are popularized. A magnetic recording apparatus, which is installed to a computer or the like, is known as one of the multimedia. At present, the development is advanced in order that the magnetic recording apparatus is miniaturized while improving the recording density of such a magnetic recording apparatus.

[0003]

A typical magnetic recording apparatus includes a plurality of magnetic disks which are rotatably installed

onto a spindle. Each of the magnetic disks comprises a substrate and a magnetic film formed thereon. Information is recorded by forming a magnetic domain having a specified magnetization direction in the magnetic film.

[0004]

In order to realize the high density recording with the magnetic recording apparatus as described above, it is demanded that the diameter of grains for constructing the magnetic film is made fine and minute and the interaction between the respective grains is lowered. However, a problem arises such that the thermal stability of the grains is lowered if the grain diameter is made fine and minute and the interaction between the grains is lowered.

[0005]

The known technique for improving the thermal stability of the magnetic disk, especially a magnetic disk having magnetization in the in-plane direction include a method in which a so-called keeper layer having soft magnetization is provided as an underlying base layer for a recording layer, and a method in which a layer having magnetization in a direction opposite to that of magnetization of a recording layer is provided. As one of the latter method, a technique is disclosed in a literature of E. N. Abarra et al. (E. N. Abarra et al., TECHNICAL REPORT OF IEICE. MR2000-34 (2000-10)) as shown in Fig. 6,

in which the thermal stability is improved by forming an Ru thin film as a magnetic coupling layer between a recording layer of CoCrPtB and a magnetization-stabilizing layer of CoCrPtB of a magnetic disk. In the structure of the magnetic disk shown in Fig. 6, when the Ru layer having a thickness of about 0.5 to 1 nm is allowed to intervene as the magnetic coupling layer between the recording layer and the magnetization-stabilizing layer, the exchange coupling is effected in an antiferromagnetic manner between the recording layer and the magnetization-stabilizing layer. Therefore, the layers have antiparallel magnetization, and hence the magnetization of the recording layer is stabilized by the magnetization-stabilizing layer. It is described in this literature that the antiferromagnetic exchange coupling effected by the Ru layer further thermally stabilizes the magnetization of the recording layer, making it possible to improve the recording and reproduction characteristics of the magnetic disk.

[0006]

[PROBLEM TO BE SOLVED BY THE INVENTION]

However, in order to realize further advanced high density recording with a magnetic recording apparatus, it is required to provide a magnetic recording apparatus which is provided with a magnetic disk that is more excellent in thermal stability than the magnetic disk disclosed in the

literature described above.

[0007]

A first object of the present invention is to provide a magnetic recording medium, especially an in-plane magnetic recording medium which is excellent in thermal stability, and a magnetic recording apparatus provided with the same.

[0008]

A second object of the present invention is to provide a magnetic recording apparatus which is excellent in stability (recording stability) of recorded information.

[0009]

A third object of the present invention is to provide a magnetic recording medium which is suitable for high density recording, and a magnetic recording apparatus installed with the same.

[0010]

[MEANS FOR SOLVING THE PROBLEM]

According to a first aspect of the present invention, there is provided a magnetic recording medium comprising:

a recording layer which is formed of a ferromagnetic material;

a magnetization-stabilizing layer which is formed of a ferromagnetic material and which stabilizes magnetization of the recording layer;

a non-magnetic layer which exists between the recording layer and the magnetization-stabilizing layer; and

an enhancing layer which exists at least one of positions between the non-magnetic layer and the recording layer and between the non-magnetic layer and the magnetization-stabilizing layer, and which increases exchange coupling between the recording layer and the magnetization-stabilizing layer.

[0011]

As a result of investigations performed by the present inventors, it has been found out that the exchange coupling between the recording layer and the magnetization-stabilizing layer can be remarkably improved by intervening a several-atoms-layered Co layer at an interface between the Ru layer (non-magnetic layer) and the recording layer and/or an interface between the Ru layer (non-magnetic layer) and the magnetization-stabilizing layer of the magnetic disk having the conventional type structure shown in Fig. 6. The layer to be intervened at the interface is not limited to Co, but may be constructed with a variety of substances capable of improving the exchange coupling between the recording layer and the magnetization-stabilizing layer as described later on. In this specification, this layer is referred to as "enhancing

layer", which functions to enhance the exchange coupling between the recording layer and the magnetization-stabilizing layer.

[0012]

According to the knowledge of the present inventors, the reason why the enhancing layer successfully improves the exchange coupling between the recording layer and the magnetization-stabilizing layer is as follows. In the case of the conventional type magnetic disk shown in Fig. 6, the recording layer of CoCrPtB and the magnetization-stabilizing layer of CoCrPtB are stacked with the Ru layer intervening therebetween. In this case, the recording layer and the magnetization-stabilizing layer effect the exchange coupling via the Ru atom layer. It is considered that the exchange coupling is effected on the basis of the fact that the electron orbits are coupled between the Co atoms in the recording layer and the magnetization-stabilizing layer via the Ru atoms. Such a coupling is also found, for example, in the coupling in an artificial lattice of a GMR head.

[0013]

However, when the interface between the recording layer and the Ru layer is observed, then the crystal grains in the recording layer are rich in Co, and the grain boundary therebetween has a Cr-rich composition, because

the recording layer is composed of CoCrPtB. As a result, it is considered that the Cr atoms, which amount is larger than that of the Co atoms, are exposed on the surface of the recording layer on the side of the Ru layer. The magnetization-stabilizing layer is also composed of the CoCr alloy (CoCrPtB) in the same manner as the recording layer. Therefore, it is considered that a large amount of Cr atoms for covering Co are exposed on the surface of the magnetization-stabilizing layer on the side of the Ru layer. It is assumed that the Cr atom layers inhibit the electron coupling between the Co atoms in the recording layer and the magnetization-stabilizing layer via the Ru atoms as described above, thereby weakening the exchange coupling between the recording layer and the magnetization-stabilizing layer. In the present invention, the recording layer or the magnetization-stabilizing layer, on which the Cr atoms are exposed on the surface, is covered with the enhancing layer. Accordingly, it is considered that the exchange coupling between the recording layer and the magnetization-stabilizing layer is improved by the exchange coupling between the atoms such as Co for constructing the enhancing layer.

[0014]

The enhancing layer may be formed of Co, Ni, Fe, or a CoNiFe alloy. Alternatively, the enhancing layer may be

formed of an alloy containing Co, Ni, or Fe and a transition metal, especially a noble metal such as Pt, Au, Ag, Cu, and Pd. The atom or the alloy as described above functions to make the coupling electronically via the non-magnetic layer so that the exchange coupling magnetic field is increased. Alternatively, when the recording layer or the magnetization-stabilizing layer is formed of a material containing Co, Ni, or Fe, it is also effective to form the enhancing layer with a material containing Co, Ni, or Fe at a concentration which is higher than a concentration in the recording layer or the magnetization-stabilizing layer.

[0015]

The enhancing layer may exist at least at one of positions between the non-magnetic layer and the recording layer and between the non-magnetic layer and the magnetization-stabilizing layer. However, it is desirable that the enhancing layer includes a first enhancing layer which exists between the non-magnetic layer and the magnetization-stabilizing layer and a second enhancing layer which exists between the non-magnetic layer and the recording layer in order to further enhance the exchange coupling between the recording layer and the magnetization-stabilizing layer.

[0016]

The magnetization-stabilizing layer may include a

first magnetization-stabilizing layer and a second magnetization-stabilizing layer, and the non-magnetic layer may include a first non-magnetic layer and a second non-magnetic layer, and a first non-magnetic layer may be formed between the first magnetization-stabilizing layer and the second magnetization-stabilizing layer, and a second non-magnetic layer may be formed between the second magnetization-stabilizing layer and the recording layer. In this case, the enhancing layer may exist at least at one of positions between the second non-magnetic layer and the recording layer and between the second non-magnetic layer and the second magnetization-stabilizing layer, and may include an auxiliary enhancing layer which exists at least at one of positions between the first magnetization-stabilizing layer and the first non-magnetic layer and between the first non-magnetic layer and the second magnetization-stabilizing layer, and which increases exchange coupling between the first magnetization-stabilizing layer and the second magnetization-stabilizing layer. Further, the auxiliary enhancing layer may include a first auxiliary enhancing layer which is formed between the first non-magnetic layer and the first magnetization-stabilizing layer, and a second auxiliary enhancing layer which is formed between the first non-magnetic layer and the second magnetization-stabilizing layer. The auxiliary

enhancing layer may be composed of the same material as that of the enhancing layer described above.

[0017]

It is desirable that the enhancing layer (as well as the auxiliary enhancing layer) has a film thickness of 0.5 to 3 nm, preferably 0.5 to 1.5 nm, in order to obtain a significant enhancing effect for the exchange coupling.

[0018]

The non-magnetic layer may be formed of Ru. However, there is no limitation thereto. It is possible to use a transition metal such as Rh, Ir, Hf, Cu, Cr, Ag, Au, Re, Mo, Nb, W, Ta, and V, and a non-magnetic alloy based on the CoCr system such as CoCrRu. Ru is preferred in order to further enhance the exchange coupling. In the present invention, the non-magnetic layer has a function to magnetically couple the recording layer and the magnetization-stabilizing layer. Therefore, the non-magnetic layer is also referred to as "magnetic coupling layer".

[0019]

In the magnetic recording medium of the present invention, the recording layer may be crystalline, and the crystalline phase may be composed of an alloy principally containing cobalt (Co). The Co alloy may contain Co as well as Cr, Pt, Ta, Nb, Ti, Si, B, P, Pd, V, Tb, Gd, Sm,

Nd, Dy, Ho or Eu, or a combination thereof.

[0020]

When the recording layer contains chromium (Cr), it is possible to form a segregation portion of Cr at the grain boundary or in the vicinity of the grain boundary between the crystal grains (magnetic grains) principally containing Co. When the recording layer further contains Ta, Nb, Ti, B, P, or a combination of these elements, the segregation of Cr is facilitated. Owing to the segregation, it is possible to reduce the magnetic interaction between the magnetic grains, and it is possible to decrease the number of magnetic grains for constructing the unit of inversion of magnetization. Therefore, it is possible to provide the magnetic recording medium which is strong against the thermal fluctuation regardless of the minute unit of inversion of magnetization, when the enhancing layer of the present invention is used in combination with the recording layer containing the foregoing additive in the CoCr alloy.

[0021]

The magnetic recording medium of the present invention may further comprise a substrate, and an underlying base layer which is formed on the substrate. In this case, the magnetic recording medium may comprise the magnetization-stabilizing layer on the underlying base layer. The substrate may be formed of glass or plastic such as

polycarbonate. The underlying base layer may be formed of Cr or Ni, or, Cr alloy or Ni alloy. The Cr alloy or the Ni alloy may contain Cr, Ti, Ta, V, Ru, W, Mo, Nb, Ni, Zr, or Al other than the base element. The underlying base layer is used in order to control the crystalline orientation and the lattice constant of the magnetic layer. The underlying base layer may be also used as a single layer or a plurality of layers.

[0022]

According to a second aspect of the present invention, there is provided a magnetic recording medium characterized by comprising:

a recording layer which is formed of a ferromagnetic material;

a magnetization-stabilizing layer which is formed of a ferromagnetic material and which stabilizes magnetization of the recording layer; and

a non-magnetic layer which exists between the recording layer and the magnetization-stabilizing layer,

wherein a magnetization curve of the magnetic recording medium with respect to an external magnetic field exhibits a hysteresis loop, a point, at which a rate of change of magnetization with respect to the external magnetic field exhibits a local maximum when the external magnetic field is lowered after magnetization is saturated,

exists in a positive area of the external magnetic field, and an exchange coupling magnetic field, which is determined from the magnetization curve, is not less than 1 kOe.

[0023]

The magnetic recording media having the magnetization-stabilizing layer of the present invention has a magnetic characteristic which is represented by a hysteresis loop as depicted by a magnetization curve as shown in Fig. 4. In the hysteresis loop shown in Fig. 4, a point, at which a rate of change of magnetization with respect to the external magnetic field exhibits a local maximum when the external magnetic field is lowered after magnetization of the magnetic recording medium is saturated, exists in an area of positive magnetic field. It is considered that the sudden change of rate of change of magnetization is caused for the following reason. That is, when the magnetization of the magnetic recording medium is saturated, both of the magnetizations of the recording layer and the magnetization-stabilizing layer are parallel, and the magnetization of the magnetization-stabilizing layer is inverted in the area in which the rate of change of magnetization exhibits the local maximum as the external magnetic field is lowered, thereby stabilizing the magnetization of the recording layer. In this area, a

minor hysteresis loop as shown in Fig. 4 may be observed. The minor hysteresis loop is shown in Fig. 5. The exchange coupling magnetic field H_{ex}, which is determined from the central point of the minor hysteresis loop, is not less than 1 kOe, preferably not less than 1.5 kOe, which is remarkably larger than that of the conventional type magnetic recording medium shown in Fig. 6. Therefore, it is appreciated that the magnetic recording medium of the present invention is excellent in thermal stability..

[0024]

In order to generate the large exchange coupling magnetic field H_{ex}, the enhancing layer may be provided at least at one of positions between the non-magnetic layer and the recording layer and between the non-magnetic layer and the magnetization-stabilizing layer.

[0025]

According to a third aspect of the present invention, there is provided a magnetic recording apparatus comprising:

the magnetic recording medium according to the first or the second aspect of the present invention;

a magnetic head which is used to record or reproduce information on the magnetic recording medium; and

a driving unit which drives the magnetic recording medium with respect to the magnetic head.

[0026]

The magnetic recording apparatus according to the present invention is excellent in recording stability over a long period of time, because the magnetic recording apparatus is installed with the magnetic recording medium which is excellent in thermal stability.

[0027]

[EMBODIMENT OF THE INVENTION]

The magnetic recording medium and the magnetic recording apparatus according to the present invention will be specifically explained below in accordance with embodiments and Comparative Examples. However, the present invention is not limited to the embodiments.

[0028]

[FIRST EMBODIMENT]

Fig. 1 shows a sectional view of a typical embodiment of the magnetic recording medium according to the present invention. A magnetic recording medium 10 comprises, on a glass substrate 20, a first underlying base layer 2, a second underlying base layer 4, a magnetization-stabilizing layer 6, a first enhancing layer 8, a magnetic coupling layer (non-magnetic layer) 12, a second enhancing layer 8, a recording layer 16, and a protective layer 18. The respective layers were formed as follows by sputtering using a DC magnetron sputtering apparatus.

[0029]

An NiAl film was formed as the first metal underlying base layer 2 on the glass substrate 1 having a diameter of 2.5 inches (6.25 cm) by sputtering using the DC magnetron sputtering apparatus. An NiAl alloy having an atomic ratio of Ni:Al = 50:50 was used for a target. The NiAl film had a film thickness of 50 nm. The Ar gas pressure during the sputtering was 0.3 Pa, and the introduced electric power was 0.5 kW. The substrate was heated to 340 °C after the pressure of the sputtering chamber was reduced to be not more than 1 x 10^{-5} Pa before starting the sputtering. The speed of film formation was about 3 nm/second under this condition.

[0030]

A CrMo film was formed as the second metal underlying base layer 4 to have a film thickness of 20 nm on the first metal underlying base layer 2. A CrMo alloy containing Mo by 27 atomic % was used for a target. The film formation condition was the same as that for the first metal underlying base layer 2.

[0031]

A CoCrPtB film was formed as the magnetization-stabilizing layer 6 to have a film thickness of 6 nm on the first metal underlying base layer 4. A $Co_{64}Cr_{20}Pt_{12}B_4$ alloy was used for a target. The film formation condition was

the same as that for the first metal underlying base layer 2.

[0032]

Subsequently, a Co film was formed as the first enhancing layer 8 to have a film thickness of 1 nm on the magnetization-stabilizing layer 6. Co was used for a target. The film formation during the sputtering was the same as that for the first metal underlying base layer 2 except that the introduced electric power was 100 W, and the spacing distance between the substrate and the target was lengthened.

[0033]

Subsequently, an Ru film was formed as the magnetic coupling layer 12 to have a film thickness of 0.8 nm on the first enhancing layer 8. Ru was used for a target. The film formation condition during the sputtering was the same as that for the first enhancing layer 8.

[0034]

A Co film was formed as the second enhancing layer 14 in the same manner as the first enhancing layer 8. The first enhancing layer 8 and the second enhancing layer 14 function to increase the exchange coupling between the recording layer 16 and the magnetization-stabilizing layer 6.

[0035]

A CoCrPtB film having magnetization in the in-plane direction was formed as the recording layer 16 to have a film thickness of 18 nm on the second enhancing layer 14. A $Co_{64}Cr_{20}Pt_{12}B_4$ alloy was used for a target. The film formation condition was the same as that for the magnetization-stabilizing layer 6.

[0036]

Finally, a carbon layer was formed as a protective film to have a film thickness of 5 nm on the CoCrPtB recording layer 16. The film formation condition was the same as that for the first metal underlying base layer 2. Thus, the magnetic disk 10 having the structure shown in Fig. 1 was produced.

[0037]

[Comparative Example 1]

A magnetic disk was produced as Comparative Example in the same manner as in the first embodiment except that the first and second enhancing layers were not formed. Fig. 7 shows a structure of the magnetic disk 50 of Comparative Example obtained as described above.

[0038]

[Evaluation of Magnetization Curve]

The magnetic characteristics of the magnetic disk produced in the first embodiment were measured as follows. The magnetic field was applied with VSM (Vibration Sample

Magnetometer) to observe the magnetization curve with respect to the external magnetic field. An obtained result is shown in Fig. 4. As appreciated from a hysteresis loop shown in Fig. 4, an area exists, in which the magnetization is suddenly lowered before the external magnetic field is zero when the external magnetic field is lowered after the external magnetic field in the positive direction is applied to saturate the magnetization. In this area, a point appears, at which the rate of change of magnetization with respect to the external magnetic field ($\delta M/\delta H$) is locally maximized. In this area, the magnetization curve depicts a minor loop which exhibits hysteresis. The reason why the minor loop appears is considered as follows. That is, the direction of magnetization of the recording layer 16 is parallel to that of the magnetization-stabilizing layer 6 before arrival at the local maximum point of the rate of change. However, the direction of magnetization of the magnetization-stabilizing layer 6 is inverted at the local maximum point.

[0039]

Fig. 5(a) shows a magnified view of the minor loop. The minor loop resides in the magnetization curve which has been obtained such that the external magnetic field in the positive direction is applied to saturate the magnetizations of the recording layer and the

magnetization-stabilizing layer, and then the magnetic field is lowered to stabilize the rate of change of magnetization, followed by increasing the external magnetic field again. It is noted that the magnetic field H, which is obtained at the center of the loop and which is located at the midpoint between the upper end and the lower end of the minor loop, is known as the exchange coupling magnetic field H_{ex} which exhibits the exchange coupling of magnetization between the recording layer 16 and the stabilizing layer 6. It has been revealed that H_{ex} is 1.4 kOe in the case of the magnetic disk obtained in this embodiment. On the other hand, in the case of the magnetic disk of Comparative Example, a hysteresis minor loop as shown in Fig. 5(b) is obtained, for which it has been revealed that H_{ex} is 0.4 kOe. Therefore, the exchange coupling force between the recording layer and the magnetization-stabilizing layer is remarkably improved in the present invention, because the first and second enhancing layers are provided at the interface between the recording layer and the magnetic coupling layer and at the interface between the magnetic coupling layer and the magnetization-stabilizing layer, respectively. For reference, it has been reported that the magnetic disk, which is disclosed in the literature described in the section of prior art, has H_{ex} of about 450 (Oe).

[0040]

Further, the volume of activation V of each of the magnetic recording media obtained in the first embodiment and Comparative Example was measured to determine the value $(Ku \cdot V)/(k \cdot T)$ as an index of thermal stability of the magnetic recording medium. As a result, the value was about 71 in the case of the magnetic recording medium of the first embodiment, while the value was 65 in the case of the magnetic recording medium of Comparative Example. Also from this fact, it is understood that the magnetic recording medium of the present invention is excellent in thermal stability. Further, in the case of the magnetic recording medium of the embodiment, Brt ($=4\pi Mr \cdot t$ (wherein Mr represents the residual magnetic field, and t represents the thickness)), which is an index to exhibit the possibility of high density recording of the in-plane magnetic recording medium, was about 44 Gμm.

[0041]

[First Modified Embodiment]

In the magnetic disk according to the present invention, the enhancing layer, which enhances the exchange coupling between the recording layer and the magnetization-stabilizing layer, may be provided at any one of the interface between the recording layer and the magnetic coupling layer (non-magnetic layer) and the interface

between the magnetic coupling layer and the magnetization-stabilizing layer. As a modified embodiment of the first embodiment, Fig. 2 shows a structure of a magnetic disk 30 in which the first enhancing layer is not formed, and Fig. 3 shows a structure of a magnetic disk 40 in which the second enhancing layer is not formed.

[0042]

[Second Modified Embodiment]

In the first embodiment, each one layer of the magnetization-stabilizing layer 6 and the magnetic coupling layer 12 has been formed. However, two layers of the former and the two layer of the latter may be formed. That is, it is possible to provide a structure comprising, on a second underlying base layer 4 of CrMo, a first magnetization-stabilizing layer of CoCrPtB, a first enhancing layer, a first magnetic coupling layer of Ru, a second enhancing layer of Co, a second magnetization-stabilizing layer of CoCrPtB, a third enhancing layer, a second magnetic coupling layer of Ru, a fourth enhancing layer of Co, a recording layer of CoCrPtB, and a protective layer of carbon. In this case, the first and second enhancing layers (auxiliary enhancing layers) function to increase the exchange coupling between the first and second magnetization-stabilizing layers. The third and fourth enhancing layers function to increase the exchange coupling

between the recording layer and the second magnetization-stabilizing layer. Alternatively, in the magnetic disk 30 shown in Fig. 2, a second magnetization-stabilizing layer, a second magnetic coupling layer, and a fourth enhancing layer may be added between the second enhancing layer 14 and the recording layer 16. Further, in the magnetic disk 40 shown in Fig. 3, a second magnetization-stabilizing layer, a fourth enhancing layer, and a second magnetic coupling layer may be added between the magnetic coupling layer 12 and the recording layer 16.

[0043]

[Second Embodiment]

A plurality of magnetic disks were produced in accordance with the same process as that used in the first embodiment. A lubricant was applied onto the protective layers of the respective disks, and then the disks were coaxially attached to a spindle of a magnetic recording apparatus. A schematic arrangement of the magnetic recording apparatus is shown in Figs. 8 and 9. Fig. 8 shows a top view of the magnetic recording apparatus, and Fig. 9 shows a cross-sectional view of the magnetic recording apparatus 60 taken along a broken line A-A' shown in Fig. 8. A thin film magnetic head, which was based on the use of a soft magnetic film having a high saturation magnetic flux density of 2.1 T, was used as a recording

magnetic head. A dual spin bulb-type magnetic head, which had the giant magnetic resistance effect, was used for the purpose of reproduction. The recording magnetic head and the reproducing magnetic head were integrated into one unit, and they are indicated as a magnetic head 53 in Figs. 8 and 9. The integrated type magnetic head 53 is controlled by a magnetic head-driving system 54. The plurality of magnetic disks 10 are coaxially rotated by the spindle 52 of a rotary driving system 51. The distance between the magnetic disk and the magnetic head surface of the magnetic recording apparatus was maintained to be 11 nm. A signal corresponding to 40 Gbits/inch^2 (6.20 Gbits/cm^2) was recorded on the magnetic disk to evaluate S/N of the magnetic disk. As a result, a reproduction output of 25 dB was obtained.

[0044]

In order to evaluate the recording stability of the magnetic recording apparatus 60, the magnetic recording apparatus 60 was placed in an environment at 80 °C at a humidity of 80 % for 100 hours. After the passage of 100 hours, the recorded signal was reproduced to measure S/N of the magnetic disk. As a result, a reproduction output of 24.3 dB was obtained. That is, the rate of decrease of the recording signal in the environment described above was 3 %.

[0045]

[Comparative Example 2]

The magnetic disk 50 of Comparative Example was incorporated into the magnetic recording apparatus in the same manner as in the second embodiment. In order to evaluate the recording stability of the magnetic recording apparatus, the magnetic recording apparatus 60 was placed in an environment at 80 °C at a humidity of 80 % for 100 hours. After the passage of 100 hours, the recorded signal was reproduced to measure S/N of the magnetic disk. As a result, a reproduction output of 22.5 dB was obtained. That is, the rate of decrease of the recording signal in the environment described above was 10 %. Therefore, it is appreciated that the magnetic recording apparatus provided with the magnetic disk of the present invention is excellent in recording stability.

[0046]

In the foregoing, the present invention has been specifically explained with reference to the embodiments. However, the present invention is not limited thereto. The first metal underlying base layer, the second metal underlying base layer, the magnetization-stabilizing layer, the magnetic coupling layer, the first enhancing layer, the second enhancing layer and the recording layer may be constructed with a variety of known materials without being

limited to the materials described in the embodiments.

[0047]

[EFFECTS OF THE INVENTION]

In the magnetic recording medium of the present invention, the exchange coupling force, which is exerted between the recording layer and the magnetization-stabilizing layer, is remarkably improved owing to the existence of the enhancing layer. Therefore, even when the minute magnetic domains are formed for the high density recording, then the thermal fluctuation scarcely occurs, and it is possible to stably retain the recorded information over a long period of time. Accordingly, the magnetic recording apparatus, which is provided with the magnetic recording medium of the present invention, is excellent in recording stability. It is possible to realize the super high density recording exceeding, for example, 40 Gbits/inch^2 (6.20 Gbits/cm^2).

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1] Fig. 1 shows a cross-sectional structure of a magnetic disk according to a first embodiment.

[Fig. 2] Fig. 2 shows a cross-sectional structure of a magnetic disk according to a modified embodiment.

[Fig. 3] Fig. 3 shows a cross-sectional structure of a magnetic disk according to another modified embodiment.

[Fig. 4] Fig. 4 shows a graph illustrating a

hysteresis loop (major loop) of the magnetic disk according to the first embodiment.

[Fig. 5] Fig. 5 shows a graph illustrating a minor loop of the hysteresis loop shown in Fig. 4.

[Fig. 6] Fig. 6 shows a sectional view illustrating a structure of a conventional magnetic disk.

[Fig. 7] Fig. 7 shows a cross-sectional structure of a magnetic disk according to a comparative embodiment 1.

[Fig. 8] Fig. 8 shows a schematic arrangement of a magnetic recording apparatus according to a second embodiment of the present invention as viewed from a position thereover.

[Fig. 9] Fig. 9 shows a sectional view as viewed in a direction of A-A' illustrating the magnetic recording apparatus shown in Fig. 8.

position thereover.

[EXPLANATION OF REFERENCE NUMERALS]

2 first metal underlying base layer

4 second metal underlying base layer

6 magnetization-stabilizing layer

8 first enhancing layer

10 magnetic disk

12 magnetic coupling force

14 first enhancing layer

16 recording layer

20 substrate

52 spindle

53 magnetic head

60 magnetic recording apparatus

[TITLE OF THE DOCUMENT] Abstract

[ABSTRACT]

[PROBLEMS] To provide a magnetic recording medium for high-density recording which is excellent in thermal stability.

[MEANS TO SOLVE PROBLEMS] An in-plane magnetic recording medium 10 has, on a substrate 20, a first underlying base layer 2 of NiAl, a second underlying base layer 4 of CrMo, a magnetization-stabilizing layer 6 of CoCrPtB, a magnetic coupling layer 12 of Ru, a second enhancing layer 8 of Co, a recording layer 16 of CoCrPtB, and a protective layer 18 of carbon. The magnetization-stabilizing layer 6 stabilizes the magnetization of the recording layer 16, and the magnetic coupling layer 12 provides the exchange coupling force which exerts between the recording layer 16 and the magnetization-stabilizing layer 6. The exchange coupling is remarkably improved by providing a first enhancing layer 8 of Co and a second enhancing layer 14 of Co in the interface between the magnetic coupling layer 12 and the magnetization-stabilizing layer6 and in the interface between the magnetic coupling layer 12 and the recording layer 16, respectively. Accordingly, it is possible to provide a magnetic recording apparatus which is excellent in recording stability over a long period of time in which the

thermal stability of the magnetic recording medium is excellent.

[SELECTED DRAWINGS] Fig. 1

[TITLE OF THE DOCUMENT] Drawing

Fig. 1

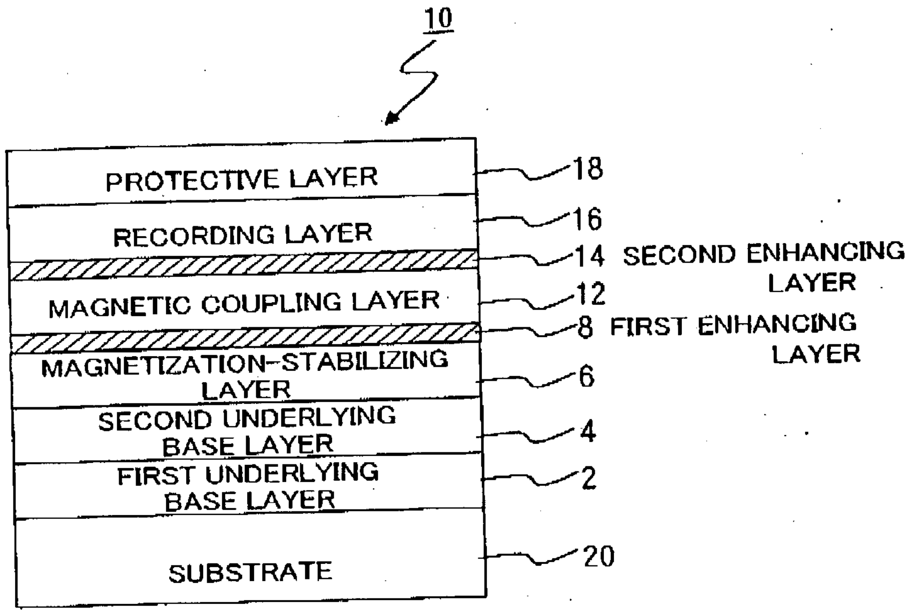


Fig. 2

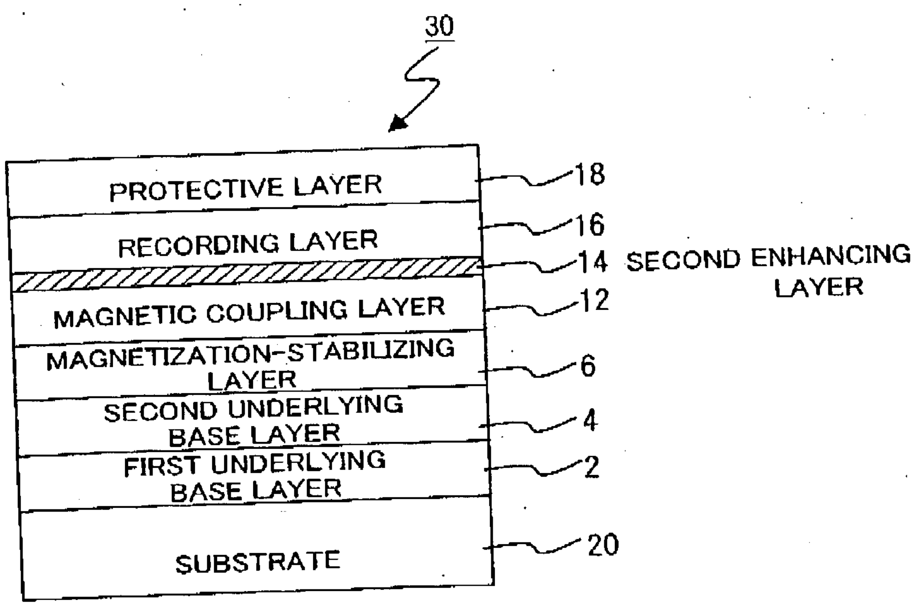

30
PROTECTIVE LAYER
18
RECORDING LAYER
16
14
SECOND ENHANCING LAYER
MAGNETIC COUPLING LAYER
12
MAGNETIZATION-STABILIZING LAYER
6
SECOND UNDERLYING BASE LAYER
4
FIRST UNDERLYING BASE LAYER
2
SUBSTRATE
20

Fig. 3

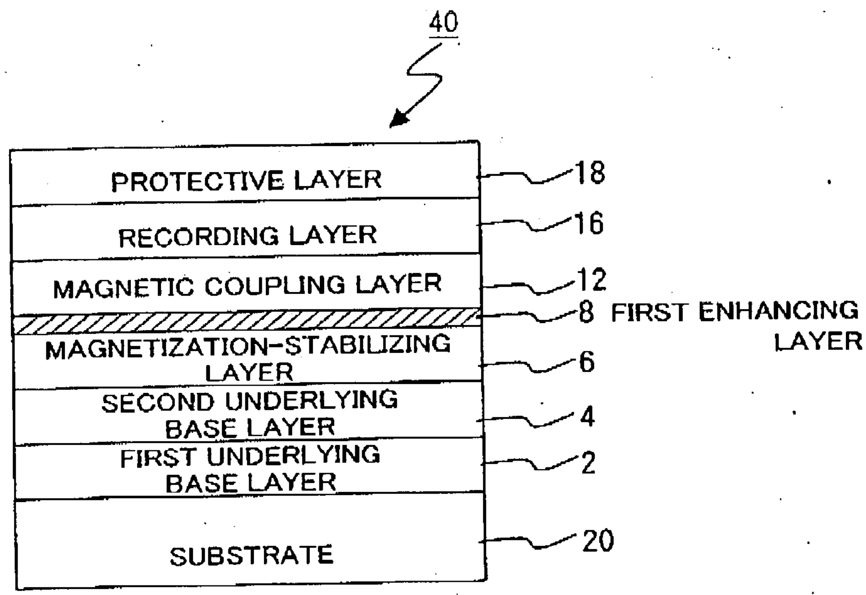

40
PROTECTIVE LAYER
18
RECORDING LAYER
16
MAGNETIC COUPLING LAYER
12
8 FIRST ENHANCING LAYER
MAGNETIZATION-STABILIZING LAYER
6
SECOND UNDERLYING BASE LAYER
4
FIRST UNDERLYING BASE LAYER
2
SUBSTRATE
20

Fig. 4

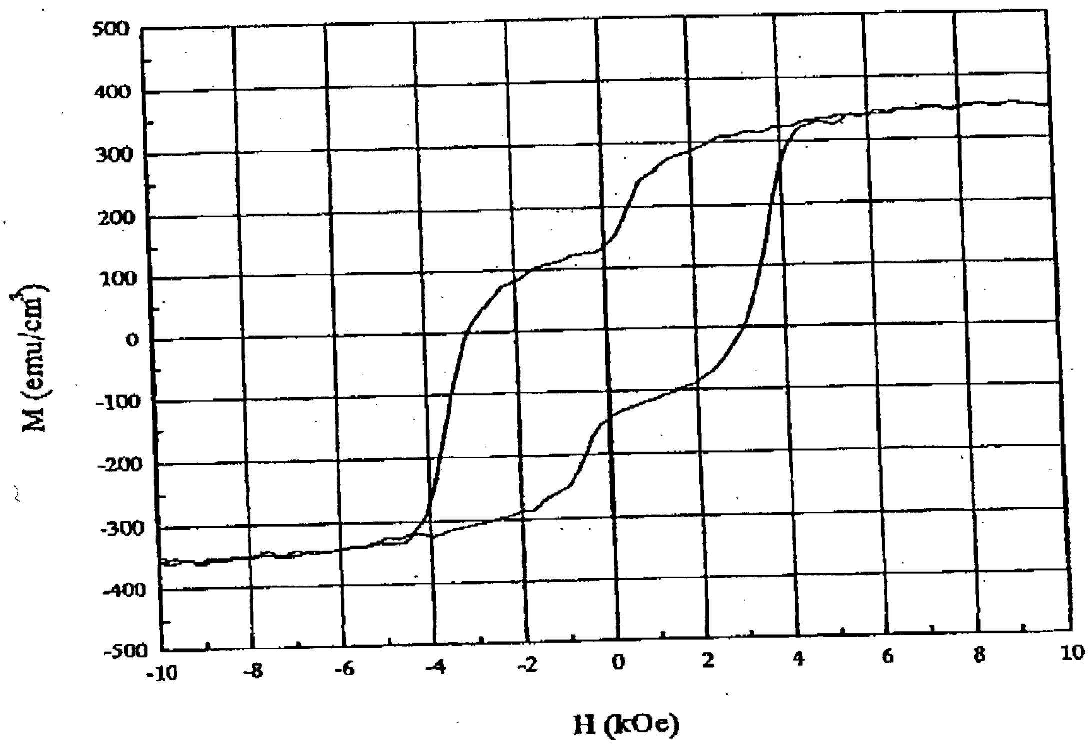
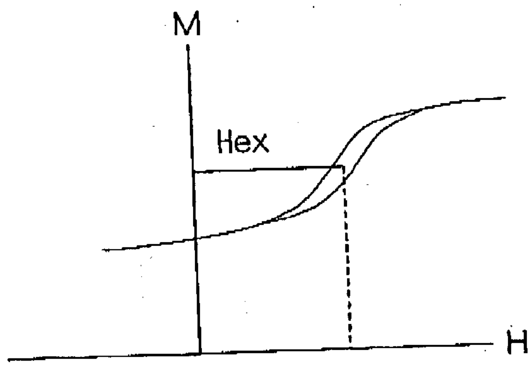

500
400
300
200
100
0
-100
-200
-300
-400
-500
M (emu/cm^3)
-10
-8
-6
-4
-2
0
2
4
6
8
10
H (kOe)

Fig. 5

(a)



(b)

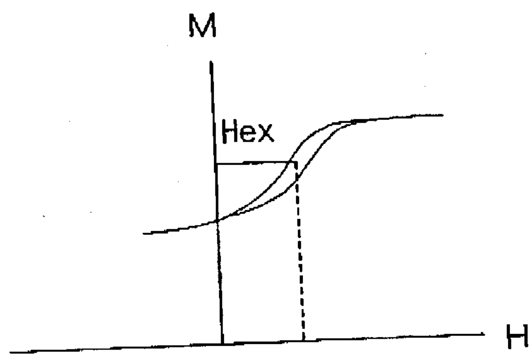


Fig. 6

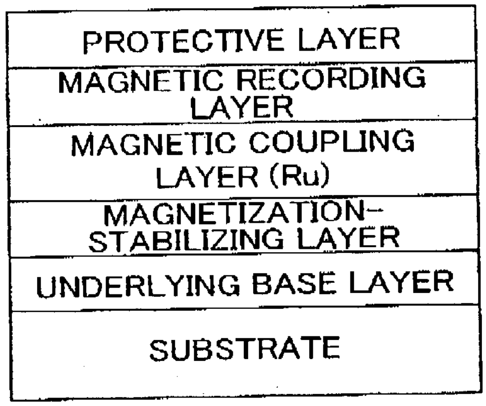

PROTECTIVE LAYER
MAGNETIC RECORDING LAYER
MAGNETIC COUPLING LAYER (Ru)
MAGNETIZATION-STABILIZING LAYER
UNDERLYING BASE LAYER
SUBSTRATE

Fig. 7

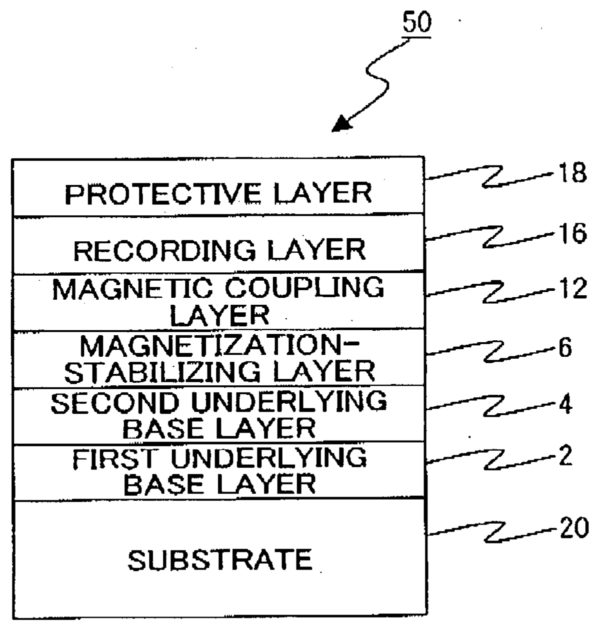

50
PROTECTIVE LAYER
18
RECORDING LAYER
16
MAGNETIC COUPLING LAYER
12
MAGNETIZATION-STABILIZING LAYER
6
SECOND UNDERLYING BASE LAYER
4
FIRST UNDERLYING BASE LAYER
2
SUBSTRATE
20

Fig. 8

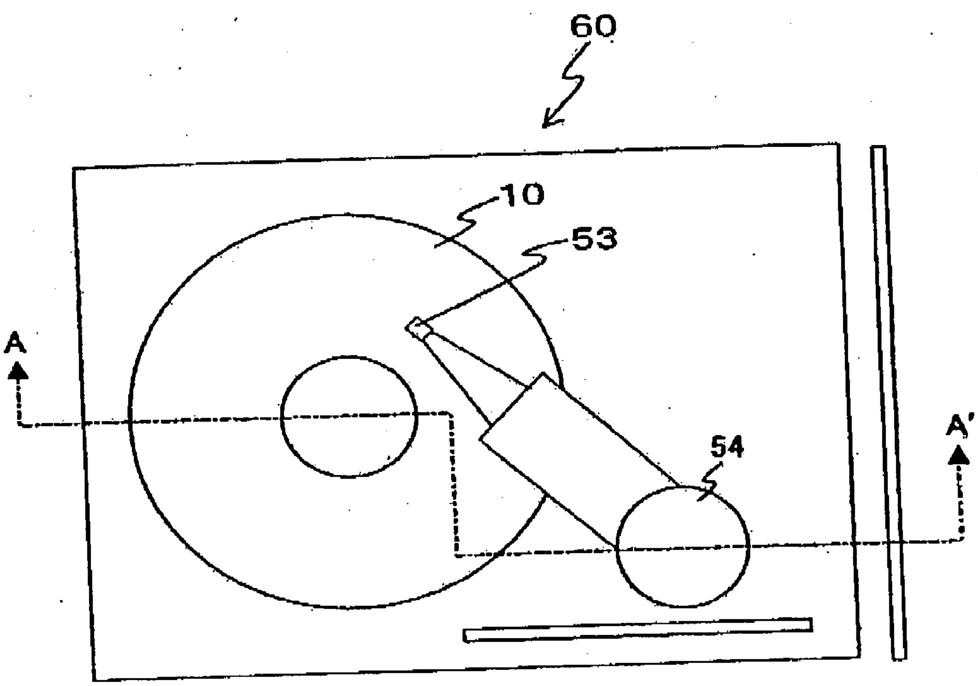


Fig. 9